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Assembly 4.0: Wheel Hub Nut Assembly Using a Cobot

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Abstract: - To achieve a flexible and adaptable assembly system (assembly 4.0) a combination of enabling resources and technologies are required. Collaborative robots (Cobots) are one such technology that can offer higher flexibility and quick adaptability in assembly systems. Cobots are becoming more common in the manufacturing industry, the use and application of cobots are constantly growing. Combining cobots with IIoT gives the possibilities to also communicate with cobots and employees to achieve an effective assembly system. This paper presents a design research experiment conducted using cobots in a lab environment. The experiment studies the use of cobots in a final assembly environment with the focus on testing feasibility, improving quality and ergonomics of a real industrial operation. The experiment setup is presented in detail and the results are discussed along with future research directions.

Keywords: cobots, flexibility, collaborative robots, Assembly 4.0, ergonomics, SII-Lab, IIoT.

1. INTRODUCTION

One of the enabling technologies of Industry 4.0 is the collaborative robot - cobot (Bortolini et al. 2017). Implementing cobots allows more flexible production systems because of their low cost, easy to set up and program, and safe to use. It has been shown that they can also increase productivity and expand the automation to new applications (Bloss 2016). Furthermore, since cobots are becoming more available and reduced in price, they can also be used to automate tasks for middle and low volume products (Fasth-Berglund *et al.*, 2016).

The level of automation often differs between different stages of the production system. During the final assembly stage, humans do over 90% of the tasks unaided by automation (Fasth-Berglund et al. 2016). To implement flexible assembly systems, Assembly 4.0, in accordance with the principles of Industry 4.0, the enabling technologies need to be implemented in the final assembly phase. Human interaction and safety aspects partly explain this low level of cobot implementations (Maurtua et al. 2017). At the same time, operators are generally very positive towards working together with cobots since, according to themselves, it can increase competitiveness, quality, productivity and improve the working conditions (Maurtua et al. 2017).

Ergonomics in the manufacturing industry has traditionally been used to eliminate harmful and unsafe work practices in an industrial environment (Resnick and Zanotti 1997). Ergonomic issues often seen during assembly tasks and can be linked to decrease in performance of operators, e.g. repetitive wrist motions and force exertion by operators that can lead to cumulative trauma disorders of the hand and wrist (Armstrong et al. 1987).

Wrist motion especially in case of manual nut assembly requires repetitive wrist motions and force exertion from the operators, which exposes them to cumulative trauma disorders of the hand and wrist. A better ergonomic condition also leads to increase in productivity (Neumann et al. 2002; Resnick and Zanotti 1997).

To increase the use of cobots in final assembly, more successful cases are needed so that new ways of thinking about automation can be formulated and digested within the community. The stations with ergonomically issues are seen to be tasks that are often used for implementation of cobots.

With that background, this paper presents a design research study of a cobot application conducted as a lab experiment. The application is based on an assembly task at Volvo Group Truck Operations and focuses on decreasing ergonomic issues among operators, maintain or decrease cycle time at the station and maintain or increase quality.

2. FLEXIBE AUTOMATION

Collaborative robots or "*Cobots*" are robot type that are intended to have direct interaction with humans by working alongside them and to have interaction with their users (Maurtua et al. 2017; Peshkin and Colgate 1999), potentially changing the way people perceive and interact with robotic technologies. Although, the word 'Cobot' was coined by Professor Michael Peshkin and Professor J. Edward Colgate in 1999 (Peshkin and Colgate 1999) it was not until fifteen years later that the cobots really became popular. Robot are now custom made to satisfy specific industry needs (Djuric, Urbanic, and Rickli 2016). Over the last decade, the market for

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Cobots has seen a huge grown and is expected to cross $1 billion by 2020 according to Forbes magazine (Press 2015). Cobots are utilized in wide range of industrial applications like automotive (Schröter et al. 2016) (Akella et al. 1999), e-waste management (Alvarez-de-los-Mozos and Renteria 2017), material handling (Gambao, Hernando, and Surdilovic 2012) and also in managing critical infrastructure facilities (Guo, Parker, and Madhavan 2007) .

The increasing demand for greater customization is pushing manufacturers for high variant production (Malik and Bilberg 2017). Collaborative applications are often less expensive than traditional robot cells and can be more flexible when it comes to route flexibility and task allocation. According to the ISO standard (ISO 10218-2:2011), a collaborative robot is defined as a robot designed for ***direct interaction*** with a human within a defined collaborative workspace. Were a collaborative workspace is defined as a space within the operating space where the robot system (including the workpiece) and a human can perform tasks concurrently during production operation (Bauer et al. 2016) (ISO 10218-1:2011, 3.5, modified SIS-ISO/TS 15066:2016). The idea of direct interaction between humans and robots is a well-discussed issue, mostly regarding safety, and historically industrial robots have been kept away from humans in a caged-off area (Sauppé and Mutlu 2015). Industrial robots have widely been used for performing repetitive and complex tasks like painting, welding, etc. which are considered hazardous and/or unergonomic for humans (Elprama et al. 2017). The common idea of when using industrial robots is often a high-volume low variant production (Malik and Bilberg 2017; Uygun and Reynolds 2017). This is changing now, robots are being used with a purpose of increasing flexibility in manufacturing (Schmidt et al. 2018) and cobots play an important role in this change Collaborative robots give the opportunity with a more open application even though it is long way left to a direct interaction between humans and robots. To start implementing a collaborative application (Bauer et al. 2016) suggests four levels of interaction between humans and cobots were the highest level is collaboration. Implementations show that industry usually starts with the two lowest level of interaction, mostly due to safety. The benefit of sharing tasks are in ergonomics for the operator, shared handling of payload, increased productivity, etc.(Kosuge and Hirata 2013).

In order to achieve higher automation flexibility in production, it is necessary to have a changeable system with the ability to upgrade and downgrade automation (Wiendahl et al. 2007). Combining collaborative robots and IIoT gives the opportunity to have a flexible level of automation but also transparency between resources. This gives the possibility to communicate data about cycle-time and quality. To measure parameters such as ergonomics other data need to be collected. To take advantage of the flexibility provided by cobots, it is important to have an infrastructure that supports it. Two design principles of Industry 4.0 applications are interoperability and decentralized decisions (Hermann, Pentek, and Otto 2016) This means that to successfully implement Assembly 4.0, cobots need to be interconnected so that they can make decisions based on data from other systems or provide data to other decision makers.

Collaborative robots usually support TCP/IP connectivity and some type of traditional Fieldbus such as Modbus TCP or PROFINET. The advantage of using Fieldbus connectivity over IP networks is related to the different communication requirements between industrial automation and normal computers. The advantage of industrial networks is related to short delays and determinism (Galloway and Hancke 2013), which are less prevalent in a human-robot collaboration scenario. This means that cobot implementations have more freedom when choosing connectivity.

3. METHODOLOGY

A design research methodology is used in conducting this experiment. Design research is a growing paradigm which treats design as a strategy for defining, developing and refining theories (Edelson 2002). The research activities in design research are iterated more often in between the construction of an artifact, evaluation of the artifact and feedback to improve the artifact (Henver 2007). This method suits best in the experiment presented in this paper where the parameters in the design are constantly changed based on the results from earlier design. The design used in conducting the experiment is explained below.

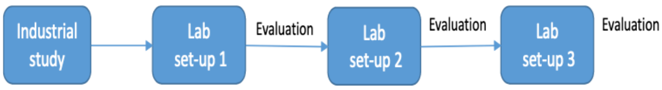

Fig. 1. Four stages involved in the design of the experiment.

Industrial Study: was conducted at the final assembly plant of Volvo Group Truck Operations. Parameters studied were ergonomic operations and quality.
Lab set-up 1: The set up in the lab differs from the industrial case study in terms of movement (from a paced line to no moving) and height of the wheel. The most important test was the feasibility of using the specific cobot, the required rotation from the cobot for finding the initial thread. After the first test, evaluation of the result was done, and improvements were done for the second set-up.
Lab set-up 2: The degree of rotation of the tool was changed to reduce the failures in finding the initial thread. After the second test, evaluation of the result was done, and improvements were done for the third set-up.
Lab set-up 3: the degrees of rotation of the tool was removed and force control along with vision recognition for bolts is introduced. After the final test, evaluation of the result was done suggestions for further tests were made.
The parameters Quality and Cycle time were observed throughout the experiment.

4. EXPERIMENTAL SET-UPS AND EVALUATIONS

This Section will explain the four different stages in the experiment.

4.1 Industrial study

The nut assembly station is a station with physical Level of Automation (LoA) from 1 to 4 e.g. a commonly called manual work station with totally manual tasks up to using a flexible hand tool, in this case, a pneumatic screwdriver. The operation used in the experiment is the totally manual assembly of the nut. The task is done as the initial nut mounting to ensure correct threads are used and for quality assurance as the power screwdriver tightens nuts with force irrespective of the location of the tread, illustrated in fig. 2.

Fig. 2. Manual Mounting of Nuts.

Mounting of nuts at present is a very unergonomic work posture with high wrist and finger moment. The most common trucks model contains from six up to ten wheels (illustrated in figure 3) and every wheel contains nine bolts and n k for the o

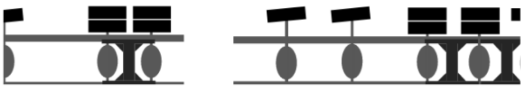

Fig. 3. Different type of trucks with three axis (six wheels) and five axis (ten wheels).

The factory assembles around 500 wheels a day in two shifts, based on the different types of trucks in assembly. The cycle time for the station is around six minutes and they are usually two operators on one station. The testing phase will produce over 250 wheels with the different testing parameters in the factory setup. Thus, 250 repetitions are used per version of the experiment to imitate one shift of assembly in the factory.

4.2 Lab set-up

The set-up is illustrated in fig. 4. The lab experiment does have some delimitations. Since it is a lab experiment the actual position of the wheel and the wheel itself was not part of the experiment. The wheel is in a steady and still position, which differs from reality. The collaborative robot "*Sawyer*"[i] is used to mount the nuts on the wheel. The selection was based on the ease of programming, higher degrees of freedom, good accuracy in measuring force control in the axis and easy for external communication through TCP7IP and higher maximum reach in comparison with UR3 and UR5. Another major advantage was the availability of inbuilt cameras and the landmarks which makes the set-up faster (Rethink Robotics 2018). A custom-made 3d-printed tool was used in this experiment. The tool containing magnets picked up the nut from the rack and placed it on the wheel hub as shown in fig. 4. The tool is also used to verify the success of the operation. The lab set-up is illustrated in Figure 4.

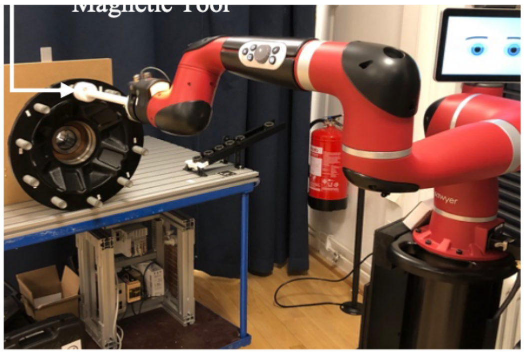

Fig. 4. Lab set-up

It is expected that the location of bolts on the wheel hub will not be at the exact same location every time. To solve this the built-in vision system is used. The vision system uses landmarks shown in figure 5 as a base of reference for positioning and calculating location coordinates for pick and place operations. Landmarks are a fiducial marker placed in the field of view of the vision system to be used as a point of reference (Rethink Robotics 2015). The novelty of Landmarks is that they are used for registering a pick and place operation without reprogramming the robot by using the built-in camera in the robot arm.

Fig.

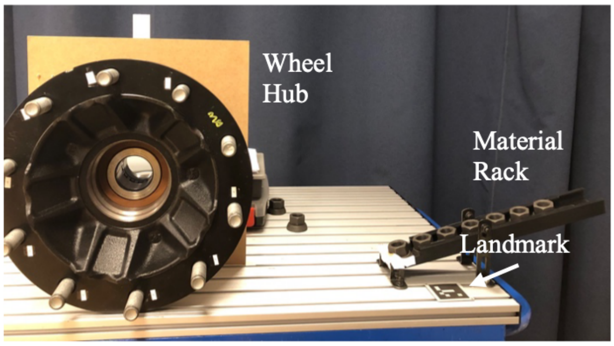

Fig. 5. A truck wheel hub used in the experiment

The verification of a successful operation is done using the retracting force from the bolt. If the retracting force is higher, the operation is successful.

Each unsuccessful operation is repeated three times before the robot moves to the next bolt. Three attempts were chosen on the basis of the prior experiments, where it was observed that the outcome was unlikely to change in further attempts after three. As cycle time was also a factor considered while choosing three as the maximum number of tires per bolt in the process of keeping the time as low as possible. The data from the experiment is collected and visualized using an IoT platform "ThingWorx". The connectivity between the robot and the IoT platform is established using a TCP-connection and Node-RED. IoT Platform is used for collecting and visualizing the data from Sawyer. Sawyer sends a start-signal and a stop-signal representing the cycle. From this cycle time can be calculated. Sawyer also sends its own unique ID for each cycle, nut number, attempt number, result and the type of error occurred.

Lab set-up 1 used maximum speed allowed by the robot. The aim here was to test the feasibility if the robot can successfully mount the nut on the wheel hub by correctly selecting the initial thread. The robot first turns counter-clockwise for 240° before turning clockwise to locate the thread and securing the nut.

Lab set-up 2 the robot turns counter-clockwise this time for 300° while the speed remained unchanged. It was observed during the testing that some nuts were unsuccessful in finding the initial threads by small margins. To overcome this problem the rotation angle was increased.

Lab set-up 3 was designed to test if vision-system is reliable enough to read the orientation of the wheel hub and locate the bolts. The wheel hub was rotated by 90° multiple times on the same spot. The wheel was moved by 50 mm in the left direction to implicate the change in location of the wheel hub.

5. RESULTS

The following section will present the most important results from the lab set-ups;

Lab set-up 1: a total of 255 cycles of nut mounting were performed. The success rate was 97.90% with an average cycle time of 127,5 sec with the tool rotation of 240°. Major concerns in this design were the mismatched initial thread due to the limitation on degrees of rotation. This was overcome in the second design where the degrees of rotation of the tool was increased to 300°

Lab set-up 2: A total of 252 cycles were performed in this design. The average cycle time was 120 seconds with the success rate of 98,78%. The errors registered in this design were located on the same two locations. The second and the ninth nut on the wheel hub.

Table 1. Comparison of results with respect to setups and corresponding parameters

Parameters	Current State	Set-up 1	Set-up 2	Set-up 3
Quality	70%	97.90 %	98.78%	99.17%
Avg. Cycle time [sec.]	145	127.5	120	107
Rotation	NA	240°	300°	NA
Torque	NA	NA	NA	YES

Lab set-up 3: The initial tool rotation was removed, and torque measurement was introduced. Torque was selected to test if the initial tool rotation operation can be removed to further increase the cycle time while keeping the quality of operation intact. A total of 254 cycles was performed in this design. The average cycle time was 107 seconds. 19 errors occurred which gives this version a success rate of 99,17%. The 19 errors involved three specific nuts. The robot measures the torque while mounting the nut on the wheel hub. The success of the mounting was measured by the retracing force generated from the magnetic tool for all three designs.

6. DISCUSSION

The importance in this was on verifying the feasibility of the use of a collaborative robot in nut assembly operation. The first setup began with testing the feasibility of the robotic application. Simultaneously, the lab setup was designed and tested. The different tested in the initial experiment was successful in demonstrating the feasibility of using a cobot in nut mounting operation. The success of the first setup also meant that the ergonomics was not an issue anymore as cobot was successful in eliminating the unergonomic operation performed by the operator. Sawyer has a lot of advance sensors and design features. Features like flexible Tool Center Point (TCP) are very useful when it comes to finding the correct threads on the bolts. Flexible TCP automatically tries to enter the bolt by self-adjusting the TCP for the correct entry point. This is based on the force detection by the tool while entering a bolt. This property was very important and helpful with respect to the quality of operation considering that the quality goal of the truck is 85% first time through (FTT). Tool rotation was introduced in the initial setup and continued to setup two. Setup two focused more on improving the quality of operation. The aim was to reduce the errors in selecting the correct initial thread. Thread selection has been very important from the quality perspective. Most quality issues in this operation arose from the mismatch of threads and/or improper selection of the initial thread. Such problems can easily be eliminated if the first thread was correctly selected. Different rotation angles were tested with multiple experimentations as discussed in the results section. Quality of operation was improved up to 98.78% in the third setup. Setup 3 focused on reducing the cycle time. With this benefit, Torque measurement was introduced for force detection while nut mounting. This operation was successful in detecting the correct mounting of nuts thus eliminating the initial tool rotation. Removal of tool rotation not just resulted in a reduction of cycle time but also helped in increasing the quality to 99.17%. The measurement of torque and retracting force are other advantages which resulted in a reduction of cycle time. Some limitations to consider are the manual moving of the wheel hub twice per experiment. This may not be the case in an industrial setting. Vision systems are widely used for object recognition and characterization (Torralba et al. 2003). A vision system is also helpful in dynamic positioning without reprogramming of robot (Huang et al. 2018) which enables a higher level of flexibility in assembly operations. A vision system is used in all three setups along with the landmarks. Use of vision detection and landmarks help in a very quick setup of the operation. As the vision system and landmarks are integrated with the inbuilt software of the cobot, even slight change in the location of the nuts or the wheel is easily detected by the vision systems and landmarks without stopping the operation or any extra programming for multiple scenarios. This results in a higher degree of flexibility of the nut mounting operation. Although the vision system worked very well, at times the camera had problems in the location of bolts on the wheel hub, this was due to the sensitivity of the camera towards the light. This limitation can be easily overcome using in proper light settings. Use of the IoT platform also brings in multiple advantages. The data from each cycle can be visualized in real time. This real-time data visualization helps in keeping track of failures on the wheel hub and can also be used in locating the source of the error. Quality problems in the bolts and/or nuts can be easily found using the data from Thingworx. As information for every nut is logged using the IoT platform, this results in one true source of data which can be useful in case of accidents or other issues related to manufacturing quality. The IoT platform can also be used ordering a new set of nuts in advance and alert/call operator for help at the station if the cobot requires assistant in operation or if it is stuck.

6. CONCLUSIONS

Globalization and increasing customer demand for product variants are putting pressure on companies to improve the flexibility in their production systems. In doing so, companies have to be careful of not letting ergonomics to be a trade-off for higher quality, flexibility, and productivity. As the use of automation has always helped in improving the quality and productivity of production systems, similar results are expected after implementation of Cobots in the assembly line. Especially in terms of eliminating bad ergonomic postures for operators and an increase in flexibility. A pre-implementation experiment of cobot for nut assembly was presented in the paper. The experiment explored the feasibility and applicability of using cobots in nut assembly on a wheel hub. To conclude, the results from the experiment suggested that the use of cobots in nut assembly is beneficial for the assembly station. Especially in the elimination of quality and ergonomics issues from the assembly station. The first test in an defined and controlled setting in the lab has been successful. The next step is to start testing in an actual industrial setting an with a robot having a longer reach as the wheel is constantly moving.

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[i] https://www.rethinkrobotics.com/sawyer/

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